UC-NRLF
B 3 062 166

LIBRARY
OF THE
UNIVERSITY OF CALIFORNIA.
RECEIVED BY EXCHANGE
Class

The University of Maine
Studies

No. 1

The Effect of Magnetization
UPON THE
Elasticity of Rods

BY

JAMES STACY STEVENS
Professor of Physics

ORONO, MAINE
OCTOBER, 1900

LIBRARY
OF THE
UNIVERSITY
OF
CALIFORNIA

Digitized by the Internet Archive
in 2007 with funding from
Microsoft Corporation

http://www.archive.org/details/effectofmagnetiz00stevrich

The University of Maine
Studies

No. 1

The Effect of Magnetization
UPON THE
Elasticity of Rods

BY

JAMES STACY STEVENS
Professor of Physics

ORONO, MAINE
OCTOBER, 1900

LIBRARY
OF THE
UNIVERSITY
OF
CALIFORNIA

A536
M3
v.1-5

*THE EFFECT OF MAGNETIZATION UPON THE ELASTICITY OF RODS

The relation existing between magnetization and the modulus of elasticity has been studied from a theoretical point of view for a number of years. The usual method of attacking the problem has been to note the changes that take place when a body already magnetized was subjected to a force which tended to bend, stretch or twist it. In 1847, for example, Matteucci examined the change in magnetization undergone by an iron rod when twisted. Further investigations along this line have been carried on by Wertheim, Wiedemann, Kelvin and others.

The general conclusion reached by these and similar experiments has been that the amount of magnetization of a body undergoes a change when the body is subjected to any kind of deforming stress. In the experiment described in this paper the problem has been attacked from the opposite point of view. Bodies were subjected to stresses which in turn tended to bend, twist and stretch them. They were then strongly magnetized and the effects upon their elastic moduli were observed and measured.

In the PHYSICAL REVIEW, Vol. II, No. 4 and Vol. III, No. 6, is described a series of important experiments which show the relation between temperature and elasticity in a wire. In one of the papers the statement was made that the results seem to indicate that the magnetizing effect of the current through the wire increases the modulus of elasticity. The increase in temperature in the wire was produced by sending a current directly through it, and also by sending a current through the helix which surrounded it. The author stated that "the magnetization produced by the first method had no appreciable effect on the result, and that if there is any difference in the effects produced upon the elasticity of a wire by magnetizing it, that difference is too small to be detected with any certainty by this experiment."

---

*We are indebted to the courtesy of the *Physical Review* for permission to use in this article material formerly published in that magazine.

175902

Mr. G. A. Shakespear (See Phil. Mag. June, 1899) while at work on another problem, reached the conclusion incidentally, "that there seemed to be an undoubted decrease in the modulus on putting on the magnetic field." He adds, however, that his observations were not quite satisfactory.

The experiments carried on in this laboratory may be divided into three parts: the effect of magnetization upon elasticity of flexion; the effect of magnetization upon elasticity of torsion; the effect of magnetization upon elasticity of traction. Considering these in the order given, the accompanying figure will make clear the method of operation. A series of carefully prepared rods, whose dimensions are given below, were in turn supported in the ordinary manner for determining the elastic modulus at points 3.2 cm. from their ends on adjustable knife-edges. In the center of the rod suspended from a hook was the load causing the deflection, and on the upper surface one of the mirrors of an interferometer. Surrounding the rod was first an air space, then a chamber for the passage of a stream of water, and on the outside two series of coils having a resistance of 54.4 ohms each. When the rod was bent by the deflecting weight the interference fringes were found in the usual manner. A sodium lamp was used as the source of light radiations. It is obvious that any change in the modulus of elasticity due to magnetizing the bar would produce a corresponding motion in the fringes seen in the mirror.

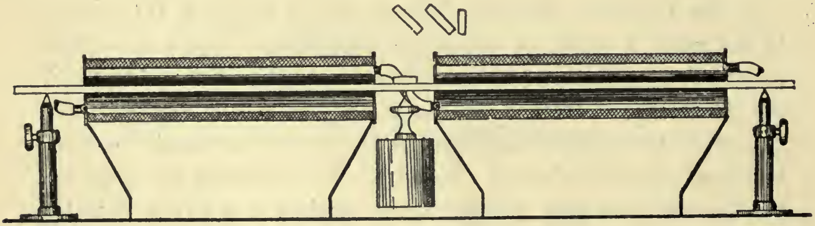


FIG. 1.

The great source of error to be guarded against in this work was the effect on the modulus due to heat. That this was eliminated will, we think, appear from the following considerations:

(*a*) A stream of water was caused to run through the chamber between the coils and the rod while the observations were made.

(*b*) The motion of the fringes appeared to be instantaneous when the current was turned on. When the circuit was kept closed for some time a creeping motion of the fringes (probably due to temperature changes) was observed.

(*c*) A copper bar of the same dimensions as those previously used was substituted, and no such instantaneous motion of the fringes was observed.

(*d*) The fringes came back to their initial position immediately when the current was turned off, when the steel rod was used.

(*e*) A thermometer reading by estimation to hundredths of a degree showed no appreciable change of temperature in the air surrounding the rod while the displacement of the fringes was being measured.

Among the difficulties encountered were:

(*a*) The arrangement of the mirrors so as to get good fringes. The conditions for producing interference were extremely unfavorable, as the adjustment of the mirror on the bar had to be made entirely by hand. It was supported on wax of such a consistency that it could be easily moved, but when once adjusted it kept its place. The difficulty here referred to, however, was one which needed only practice and patience to overcome, and whenever the observations were recorded the fringes were sufficiently distinct.

(*b*) Although the apparatus was mounted in a basement laboratory, on a stone slab supported by a brick foundation which did not come in contact with the floor or any other part of the building, a clock striking four stories above it caused a rhythmical motion of the fringes. It may be judged from this illustration that the work had to be done at such times as we could find the building free from ordinary disturbances.

(*c*) Another difficulty was encountered at first arising from the use of homogeneous light, and the consequent similarity of the fringes. With the mirror adjustments used here it would have been next to impossible to have obtained the colored fringes, which may readily be identified; but it was soon found that the displacements were never of an order of magnitude greater than one wave-length, and therefore the necessity of identification was avoided.

The following data were employed:

Length of rods,	66.3 cm.
Distance between knife-edges,	60.0 "
Breadth of rods,	1.0 "
Thickness of rods,	0.54 "
Length of magnetizing helix,	53.0 "
Number of layers of wire,	9.6
Number of turns of wire,	7026.0
Minimum current used,	0.12 amp.
Maximum current used,	0.82 "
Number of turns per cm.,	132.0

In the tables which follow are shown the current, the magnetizing force, the intensity of magnetization and the accompanying displacement of the fringes. In every case the direction of displacement indicated an *upward* movement of the mirror, and hence an *increase* in the modulus of electricity.

TABLE I.

STEEL BAR. LOAD 1K.

Current in Amperes.	Magnetizing Force.	Intensity.	Displacement in Wave-lengths.
0.46	77.5	A nearly uniform intensity of about 700.	0.06
0.54	89.6		0.15
0.57	93.8		0.20
0.60	99.6		0.25
0.64	106.2		0.38
0.66	108.7		0.45
0.68	112.9		0.50
0.71	117.9		0.50
0.75	124.5		0.63

TABLE II.

STEEL BAR. LOAD ½K.

Current in Amperes.	Magnetizing Force.	Intensity.	Displacement in Wave-lengths.
0.44	73.0	A nearly uniform intensity of about 700.	0.06
0.45	74.6		0.06
0.46	77.5		0.06
0.62	102.9		0.13
0.64	106.2		0.19
0.65	107.9		0.25
0.66	109.6		0.25
0.68	112.9		0.31
0.71	117.9		0.50
0.75	124.5		0.50

TABLE III.

WROUGHT IRON BAR. LOAD 1K.

Current in Amperes.	Magnetizing Force.	Intensity.	Displacement in Wave-lengths.
0.12	19.9	389.7	0.08
0.15	24.9	516.5	0.22
0.27	44.9	735.2	0.28
0.33	54.1	838.2	0.35
0.38	61.3	....	0.38
0.54	89.7	....	0.48

TABLE IV.

WROUGHT IRON BAR. LOAD ½K.

Current in Amperes.	Magnetizing Force.	Intensity.	Displacement in Wave-lengths.
0.16	26.6	615.1	0.20
0.33	54.8	730.0	0.50
0.43	71.6	838.2	0.63
0.60	99.6	868.8	0.75
0.76	125.9	1075.0	0.88

DISCUSSION OF RESULTS

The difficulties encountered in making these observations, and the fact that it was necessary to make them quite rapidly conspired to render the results recorded in the last columns of the tables rather unreliable as quantitative measurements. So far as practicable, however, they represent the mean of several observations taken by two persons. If they were plotted either with the magnetizing force or the intensity of magnetization they would not yield a straight line or any other regular curve. In every case, however, an increase of current was accompanied by an increased displacement. In the case of the steel bar it was necessary to keep the current within a limited range, and as shown in the tables the intensity remained nearly constant. With the wrought iron we were able to use a greater range of current and secured a greater deviation in the displacement column.

The following may be set down as the results of the experiment.

(*a*) The modulus of elasticity of wrought iron and steel increases with magnetization.

(*b*) In the case of steel little difference was observed for loads of 1 K and ½ K. In the case of wrought iron the smaller load gave the greater displacement when equal magnetizing forces were used.

The second part of the investigation had reference to the elasticity of torsion.

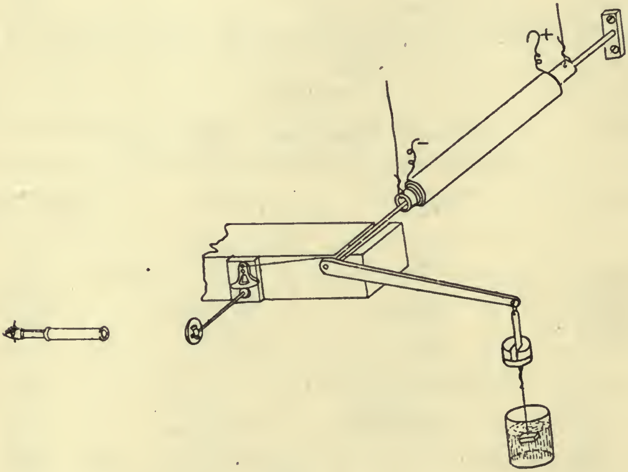


FIG. 2.

In these experiments three styles of cylindrical rods were employed: one of iron, 183 cm. long and 0.48 cm. in diameter; one of steel of the same dimensions, and lastly the iron rod was reduced in length to 163 cm. To magnetize these rods a coil of two layers of No. 16 wire was wound in 1,612 turns. The length of the coil was 132.1 cm. One end of the rod was rigidly screwed into an iron plate, fastened to a solid wall, and to the other was attached an arm carrying a weight at the opposite end which supplied the force of torsion. The arrangement of the apparatus is shown in the accompanying figure.

After the rod had been twisted by the application of the given weight the current was sent through the coil, and in every case where the current was sufficiently strong a *rising* of the weights was observed, showing that the magnetizing effect was such as to increase the torsional elasticity. In order to damp the vibrations a small weight suspended in a jar of water served as a dash pot. The following table shows approximately the angles through which the rods were twisted by the loads applied.

Moment of Torsion (dynes).	Angle of Torsion (degrees).
6.3×10^6	2
4.8×10^7	15
9.8×10^7	30
13.6×12^7	39

To measure the change which took place in the angle of torsion when the rods were magnetized, I employed two methods: first, a mirror was fastened to the arm and the rotation of the rod was measured by a telescope and scale; secondly, in case the rotation was small, a device shown in the figure was employed which multiplied the scale readings 9.43 times.

In the following tables are shown the current, magnetizing force, scale readings and the angle representing the corresponding rotation of the rods.

TABLE I.

Iron rod, 183 *cm. long. Moment of Torsion* 9.8×10^7 *dynes.*

Magnetizing Force.	Scale Readings.	Angular Rotations (Minutes).	Magnetizing Force.	Scale Readings.	Angular Rotations (Minutes).
7.7	0.01	0.3	50.0	0.94	25.5
13.7	0.02	0.6	54.6	0.97	26.3
19.9	0.12	3.3	71.9	1.1	33.0
23.0	0.29	7.8	76.5	1.2	36.0
29.1	0.45	12.3	79.6	1.2	36.0
32.1	0.66	18.0	91.9	1.2	36.0
35.2	0.72	19.2	104.0	1.3	39.0
38.3	0.74	20.1	117.8	1.3	39.0
42.8	0.83	22.5	127.0	1.3	39.0
44.3	0.87	23.7	137.7	1.4	42.0

TABLE II.

Iron Rod, 183 *cm. long. Moment of Torsion* 4.8×10^7 *dynes.*

Magnetizing Force.	Scale Reading.	Angular Rotations (Minutes).	Magnetizing force.	Scale Readings.	Angular Rotations (Minutes).
4.6	0.01	0.3	36.7	0.90	24.6
9.2	0.02	0.6	39.8	0.92	25.2
13.8	0.23	6.6	47.4	1.00	27.3
16.8	0.35	9.6	52.1	1.06	28.8
19.9	0.46	12.6	64.3	1.13	30.9
23.0	0.62	16.8	76.5	1.22	33.3
26.0	0.69	18.9	82.3	1.23	33.6
30.6	0.78	21.3	90.3	1.25	34.2
32.1	0.80	21.9			

Table III.

Steel Rod, 183 cm. long. Moment of Torsion 9.8×10^7 *dynes.*

Magnetizing Force.	Scale Readings.	Angular Rotations (Minutes).	Magnetizing Force.	Scale Readings.	Angular Rotations (Minutes).
7.7	0.1	2.6	76.5	0.2	5.2
15.3	0.1	2.6	91.8	0.3	7.8
22.9	0.1	2.6	137.7	0.3	7.8
30.6	0.1	2.6	145.4	0.3	7.8
35.2	0.1	2.6	153.0	0.4	10.4
38.3	0.2	5.2	168.3	0.4	10.4
58.1	0.2	5.2	214.1	0.5	13.0
61.2	0.2	5.2			

Table IV.

Iron Rod, 163 cm. long. Moment of Torsion 9.8×10^7 *dynes.*

Magnetizing Force.	Scale Readings.	Angular Rotations (Minutes).	Magnetizing Force.	Scale Readings.	Angular Rotations (Minutes).
12.4	0.05	1.3	79.4	0.4	10.0
19.9	0.15	3.8	107.1	0.4	10.0
27.5	0.2	5.0	130.0	0.5	12.5
30.6	0.2	5.0	137.0	0.5	12.5
38.3	0.3	5.0	153.0	0.5	12.5
61.2	0.3	7.7	183.6	0.6	15.1
68.8	0.4	10.0	198.9	0.6	15.1
76.5	0.4	10.0			

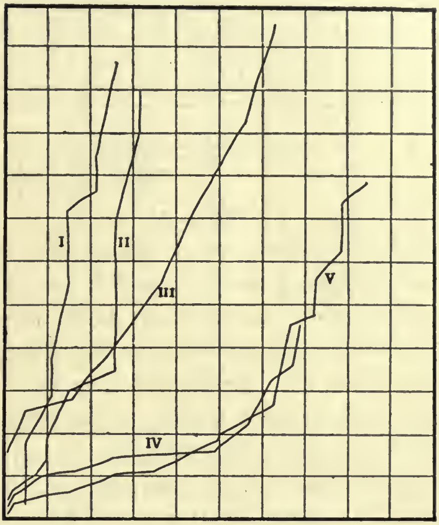
Table V.

Iron Rod, 183 cm. long. Moment of Torsion 13.6×10^7 *dynes.*

Magnetizing Force.	Scale Readings.	Angular Rotations (Minutes).	Magnetizing Force.	Scale Readings.	Angular Rotations (Minutes).
33.7	0.01	0.6	91.8	0.67	18.3
47.4	0.04	1.2	183.6	1.14	28.2
53.6	0.08	1.8	229.5	1.14	31.2
56.6	0.26	7.2	306.0	1.17	31.8
64.3	0.48	13.2	382.3	1.19	32.4
82.6	0.58	15.9	405.5	1.22	33.3

Measurements were also taken with no weight added to the arm of torsion except the small one used with the dash pot. The moment of torsion was 6.3×10^6 dynes. While a deflection was noted with each magnetizing force used, the scale readings were quite irregular and the zero not constant.

By use of the device for multiplying the scale readings, it is thought that the error in estimation need not exceed eight seconds.



The above curves were plotted with magnetizing force divided by 4 and corresponding angles of rotation expressed in minutes as co-ordinates. *I* is for the steel rod, *II* the short iron rod, *III, IV* and *V*, the longer iron rod with moments of force 13.6×10^7, 4.8×10^7 and 9.8×10^7 dynes respectively. Without doubt, the lack of regularity of the lines is due in large measure to errors of observation.

From the general consideration of the experiments, and the inspection of the tables and plots, the following conclusions may, I think, be written down:

1. Magnetization of an iron or steel rod increases its torsional elasticity. This would be expected from the results of the experiments mentioned in the first part of this paper dealing with its effects upon elasticity of flexion.

2. The effect is greater in iron than in steel rods of the same dimensions.

3. The increase in elasticity varies with the length of the rod.

In the third part of the investigation the effects upon the modulus of elasticity by traction was studied. Figure 3 shows the general form of the apparatus.

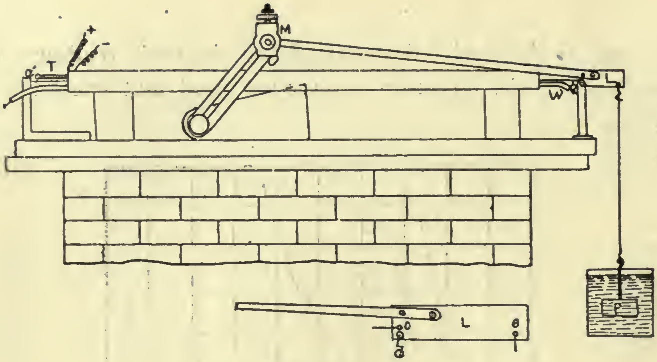


FIG 3.

A coil of wire was wound on a brass tube through which passed a stream of running water, in which was carried the wire to be tested. One end of the wire was fastened to a rigid iron support and the other was attached to a bent lever with a multiplying power of about 11. At the other end of the lever were attached weights which gave a tension on the wire of 5.39×10^6, 10.78×10^6 and 19.6×10^6 dynes respectively. The changes in length were communicated to another arm of the same lever, which multiplied the effect 110 times. The free end of this lever moved under the field of a micrometer microscope. A thermometer whose bulb was inserted in the stream of water completed the arrangement.

DATA

Length of coil	131.1	cm.
No. of turns of wire	1612.0	
Diameter of wire	0.13	cm.
Length of wire tested	175.0	cm.
Diameter of wire A	0.73	mm.
Diameter of wire B	0.98	mm.
Tension weight A	5.5	kgm.
Tension weight B	11.0	kgm.
Tension weight C	20.0	kgm.
Multiplying power of first lever	11.0	
Multiplying power of second lever	110.0	
Microscope constant 28.33 turns per min.		
Current	2.2—7.6	Amp.

The procedure consisted in setting the cross wires of the microscope on some point for zero, then turning on the current and noting the deflection of the end of the lever. The tables which follow give the current, zero readings, the difference, and the change in the length of the wire reduced to centimeters.

TABLE I.

Wire B. Tension B.

Current.	Initial Reading.	Final Reading.	Difference.	Change in Length in cms.
2.12-2.18 amps.	42	88	46	15×10^{-6}
	75	18	43	14 "
	79	10	31	10 "
	68	16	48	15 "
	82	26	44	14 "
	79	15	36	11 "
	59	92	33	11 "
	41	80	39	12 "
	4	36	32	10 "
	81	14	33	11 "
	56	5	49	15 "
	51	87	36	11 "
	41	74	33	11 "

The above table shows complete readings in order to set forth the degree of constancy which the experiment afforded. This was about an average set of readings. The tables which follow this give the mean only of a number of readings, usually about 12.

TABLE II.

Wire B. Tension B.

Current amps.	Change in Length cms.	Current in amps.	Change in Length cms.
2.62	13×10^{-6}	5.30	26×10^{-6}
3.95	16 "	6.50	48 "
4.50	20 "		

TABLE III.

Wire B. Tension A.

Current amps.	Change in Length cms.	Current amps.	Change in Length cms.
2.6	6.0×10^{-6}	4.2	12.8×10^{-6}
3.5	9.0 "	4.7	16.0 "

TABLE IV.

Wire A. Tension A.

Current amps.	Change in Length cms.
4.0	12.8×10^{-6}
7.7	25.4 "

TABLE V.

Wire B. Tension C.

Current amps.	Change in Length cms.	Current amps.	Change in Length cms.
6.9	15.0×10^{-6}	7.6	19.2×10^{-6}
7.1	16.1 "		

TABLE VI.

Wire B. Tension B.

Current amps.	Change in Length cms.
6.8	10.2×10^{-6}
8.0	11.2 "

From the tables we may draw the following conclusions:

1. The modulus of elasticity of traction *increases* when the body is magnetized.

2. The increase is fairly proportional to the magnetizing force.

3. With the same wire the change in the modulus varied with the stretching weight.

4. With wires of different cross sections, stretched by the same load, the change in modulus was greater with the smaller wire.

It was considered that errors due to change in temperature were entirely avoided or reduced to negligible quantities. The stream of water in which the wires were placed kept the temperature so constant that changes greater than 0.1 degree did not occur in fifteen minutes. Moreover the change in the length of the wire due to magnetization was noted in about fifteen seconds. It may therefore be assumed that temperature changes during the time in which the observations were made were about of the order of 1-600 of a degree F. This was about ⅓ of the value of the smallest observed change. The principal test for absence of temperature effects, however, was the fact that, as in former experiments already noted, the changes in length due to magnetization are suddenly and easily distinguished from the temperature effects, which are creeping. Whatever changes may be due to temperature must of course be added to the results above given since they take place in the opposite direction. The same remarks will apply to changes in the length of the wires due to magnetization alone.

In connection with this part of the work the attempt was made to measure the effects of magnetization upon the elasticity of compression. The experiment proved an interesting one although purely negative results were obtained. A drawing of the apparatus and data for the observations follow.

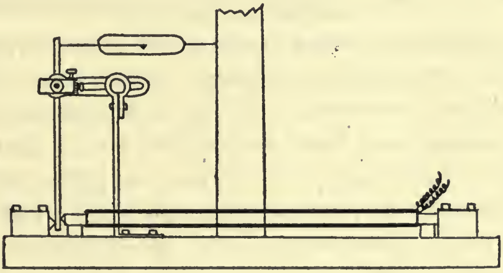


FIG. 4.

DATA

Length of rod........................ 134.5 cm.
Diameter of rod...................... 2.54 cm.
Resistance of coil................... 3.3 ohms.

Wound with No. 16 double cotton covered magnet wire 1830 turns.

Ratio of power arm......................1 to 120.
Ratio of index..........................1 to 106.7
Constant of micrometer microscope, 28.33 turns to 1 mm.

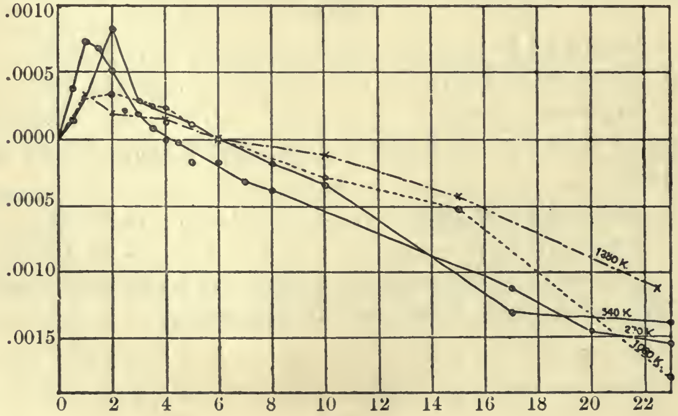
The tables which follow are self explanatory.

270 kilos.		540 kilos.		1080 kilos.	
C.	*change.*	*C.*	*change.*	*C.*	*change.*
.5	.00038+	.5	.00014+	1.	.00030+
1.	.00073+	1.	.00031+	2.	.00034+
1.5	.00068+	2.	.00083+	4.	.00023+
2.	.00051+	3.	.00028+	6.	.00000
2.5	.00021+	3.5	.00025+	8.	.00021−
3.	.00019+	4.	.00012+	10.	.00029−
3.5	.00009+	5.	.00011+	15.	.00052−
4.	.00000	6.	.00000	23.	.00180−
4.5	.00002−	8.	.00018−		
5.	.00017−	10.	.00034−		1350 kilos.
6.	.00018−	17.	.00130−	*C.*	*change.*
7.	.00032−	23.	.00139−	1.	.00033+
8.	.00039−			2.	.00019+
17.	.00112−			4.	.00015+
20.	.00145−			6.	.00000
23.	.00154−			10.	.00012−
				15.	.00043−
				22.5	.00112−

Current in Amperes. Changes in mm. +Increase in length of bar. —Decrease in length of bar.

It was thought that since the pressures applied were not of an order which represented the elastic limit, these results only represented the extension of the bar due to magnetization. If sufficient compressing force was applied to the rod it ought to follow, from the analogy of the former cases, that magnetization would extend the bar, and other things being equal, the extension would vary approximately with the compressing force.

When these results came to be plotted it was found that very little difference could be detected for changes in compressing force varying from 270 to 1350 kilos. It is noticeable also that



the curves resembled those of other experimenters who have tested the changes in length of a bar when magnetized. They are particularly similar to those obtained by Dr. L. T. More. (See PHYSICAL REVIEW, November-December, 1895.)

GENERAL CONCLUSION

These investigations were undertaken with no previously formed theory as to their outcome. They seem quite clearly to establish the fact that magnetization increases the elastic moduli of metals. Just in what manner this is accomplished cannot be told until we are more familiar with both magnetization and elasticity. Following the molecular theory of magnetization it might be assumed that the molecules of a body, already under elastic stress, are so reädjusted by the magnetizing force that they tend to come together and occupy a smaller amount of space. Under normal conditions, however, the reverse is true, since magnetization increases the length of iron rods.

So far as these results have any bearing upon the theory of the constitution of bodies we seem to be able to draw this conclusion: the molecules of a body under elastic stress behave when magnetized in a different manner from bodies not subjected to such stress.

It ought to be stated here that material assistance in the construction of apparatus and the taking of observations was given me by Messrs. Herbert Grove Dorsey and Stanley Sidensparker, instructors in the department of physics.

THIS BOOK IS DUE ON THE LAST DATE
STAMPED BELOW

AN INITIAL FINE OF 25 CENTS
WILL BE ASSESSED FOR FAILURE TO RETURN
THIS BOOK ON THE DATE DUE. THE PENALTY
WILL INCREASE TO 50 CENTS ON THE FOURTH
DAY AND TO $1.00 ON THE SEVENTH DAY
OVERDUE.

NOV 13 1940 M

MAR 12 1947

SANTA BARBARA
INTERLIBRARY LOAN

JUL 10 1978

REC. ILL JUL 31 1978

REC. CIR. AUG 7 '78

LD 21

10m-5,'21

AS36
M3
v.1-5
Maine
175902
2